

Recent Experimental Results with LASS-Based Ultra-Wideband Radar Systems

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ABSTRACT

This paper describes the design and experimental performance of an ultra-wideband (UWB) demonstrator source/antenna system. The system is composed of the following elements: 1) a low impedance ($<1/4 \Omega$) source based on Light Activated Silicon Switches (LASS) operating in the 50 MW range with a rise-time of less than 100 ps, 2) a rise-time conserving transformer with an impedance ratio in excess of 200:1 and a power efficiency of greater than 50%, 3) a TEM antenna, 4) a diode laser pumped laser system for light activation, and 5) a receiver for detecting the radiated waveforms.

INTRODUCTION

For an UWB radar to be effective for target detection and/or neutralization, the signal generator must be capable of generating high peak power pulses (megawatts to gigawatts) with rise-times less than 100 ps. ECR has been developing an UWB radar in which the generator (source) is composed of one or multiple light activated silicon switches (LASS) mounted on a microstrip transmission line (MTL). The switches discharge the transmission line to generate a high power pulse of microwave energy. This source has been shown to be capable of meeting the high peak power and fast rise-time requirement of an UWB radar. The rationale behind this method of high power, short pulse microwave generation has previously been discussed.¹ In summary, the key to generating high power pulses is in the integration of LASS devices with low impedance MTLs. The MTL is made from a high quality thin film dielectric which is capable of a power flow (Poynting vector) in excess of 76 GW/cm² at a electric field strength of 10 kV/mil. For efficient radiation of the generated power, the low impedance MTL is then transformed to match the impedance of free space. Transformers with impedance ratios greater than 200:1, which preserve the 100 ps electrical rise-time, have been fabricated and tested.² Figure 1 shows the complete microwave system, which consists of the source, transformer/antenna, pulse charger, and short pulse diode pumped laser system. Since the system consists of all solid state elements, it is compact, rugged, and has long life.

The following sections report the latest developments on the source, antenna, and compact laser system. The transformer is described in another paper in these proceedings and, to avoid redundancy, is omitted. ECR, along with the other team members, is planning a demonstration of this system before 1994.

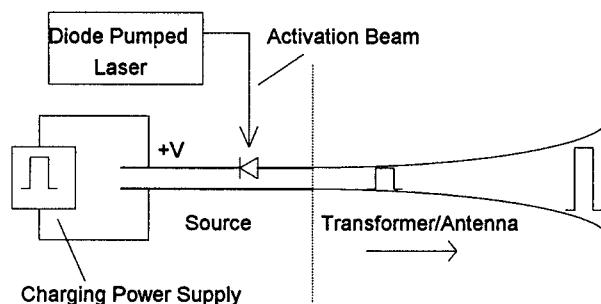


Figure 1. A LASS based microwave generator.

LASS SOURCE

The LASS source produces a high peak power pulse by discharging a low impedance MTL in a single round trip (~ 500 ps). The characteristic impedance of the MTL is between $1/10 \Omega$ and $1/4 \Omega$, depending on the width of the conductors and the thickness of the insulating material. Low impedance (high current density) is utilized to maximize both the power and speed concurrently. At this impedance level, the switch must be capable of conducting 30-40 kA of current at an average current density exceeding 100 kA/cm². To conduct a current of this level requires that the switch operate in the "linear" mode. In the "linear" mode, the laser energy is high enough to generate the total number of electron-hole pairs required for conduction. The benefits of "linear" operation are: 1) no delay between the arrival of the laser pulse and the fall of the voltage on the switch (low jitter), 2) large average current densities can be carried, 3) "on state" voltage drop is low, which enables the switch to control high average powers and multiple switches can operate in series, and 4) long lifetime at high power. These benefits allow a single source to generate not only high peak and average powers but complex waveforms of various frequency contents by sequential switching of series switches³.

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Scaling to gigawatts of peak power is possible because the absolute timing between multiple sources allows their output power to be efficiently combined without loss of rise-time. The output power of four "linear" switches have been combined, in parallel, with 100% efficiency and the combined pulse had a rise-time of 78 ps.

Unlike silicon, GaAs photoconductive switches can be switched into conduction with a low light energy. In this mode, termed "non-linear" or "high gain", the light supplies only minimal carriers, the rest being generated by impact ionization. Since the carrier creation by ionization takes time, there is a delay between the creation of the initial electron-hole population and the fall of the voltage on the switch. This delay, which is a function of the blocking electric field, results in source to source jitter which limits the ability to scale "non-linear" switches to higher powers. Also, in the "non-linear" mode the "on state" electric field is high (3.5-8.5 kV/cm), resulting in substantial dissipation during conduction.⁴ This reduces average power handling and eliminates the ability to utilize sequential switching of series switches for waveform crafting. The life-time of "non linear" switches is reduced at high power because not only is the "on state" dissipation high, but the current is conducted in one or more filaments, resulting in isolated melt zones. While "non-linear" switches are of importance for low power (1-2 MW) applications, the stringent demands on both power and speed on an UWB generator dictate "linear" mode switching.

Figure 2 shows a 210 MW electrical pulse generated by switching, with 15 mJ of laser energy, a LASS mounted on an $1/8 \Omega$ MTL. The switch blocked 12 kV (67.5 kV/cm) and conducted 40 kA at a current density of 111 kA/cm². The switch power density was 7.5 GW/cm³ and the power flow down the MTL (Poynting vector) was 5.2 GW/cm². The total volume (switch plus transmission line) was less than one cubic centimeter. Combining the power from multiple sources will enable the generation of gigawatts of RF power. The same switch operated in a Blumlein circuit would be able to generate 400-500 MW directly. Currently, ECR is investigating the fabrication of Blumleins for this application.

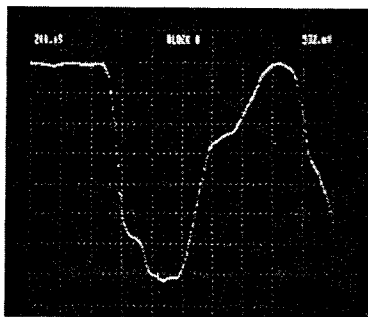


Figure 2. Oscilloscope trace of a 210 MW pulse. (200ps/div, 700V/div)

LASS devices not only possess high power, but long life at high power. Life-time testing been conducted on two separate sources. The first was an 8 cm wide source which produced 30 MW of peak power for over 55 hours at 10 Hz (2 million shots) before the MTL material failed⁵. Only 2.25 mJ of laser energy was required to activate this source (75 μ J/MW). Another source operated for

150,000 shots at 60 MW with 2.25 mJ of laser energy (37 μ J/MW). A high repetition rate laser, which will reduce the number of hours required to test a source, is currently under development.

TRANSFORMER/ANTENNA

Since the power is generated in a low impedance MTL, an impedance transformer is required in order to efficiently radiate the generated power. The design and testing of high impedance ratio transformers is discussed in a separate paper in these proceedings⁶. They transform over 200:1 in impedance without loss of pulse rise-time and at greater than 50% efficiency. The transformer is either coupled into a 50 Ω coaxial connector or directly flared into a TEM horn. Figure 3 shows the complete UWB source/transformer/antenna. The source is composed of a single LASS device mounted on a $1/3 \Omega$ MTL. The source directly feeds the transformer. The antenna was characterized with a swept CW signal from 0.5 GHz to 5 GHz. At 5 GHz the gain is 15 dB with a full beam angle of 40 degrees and drops off to zero at 500 MHz. A receive antenna of the same design was also fabricated. Low power testing has also been performed at ECR to verify operation of the LASS. Final testing at high power (20-50 MW) will be performed before 1994.

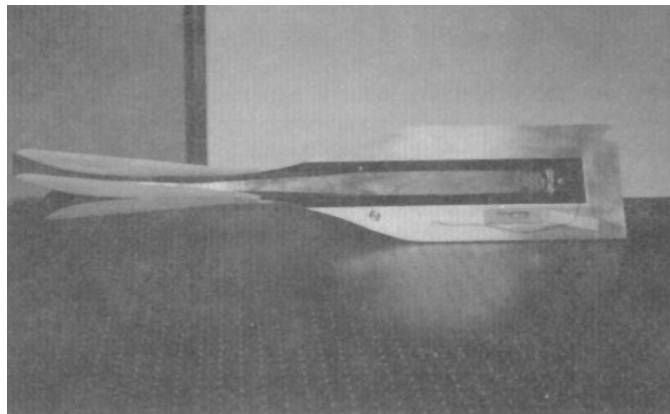


Figure 3. Photograph of a complete source, transformer and antenna.

COMPACT LASER SYSTEM

The laser system for the UWB radar must be capable of delivering millijoules of energy to switch hundreds of megawatts to gigawatts of RF power. Millijoules of energy in less than 200 ps cannot be obtained by a simple laser diode which is used to activate a "non-linear" switch. To obtain these energy levels, energy storage in a lasing medium is required. To store energy in a lasing medium, it is either "pumped" by a flash lamp or a laser diode tuned to the absorption band of the laser material. Flash lamp pumped systems have been in existence for over 30 years. They are typically less than 0.1 % efficient and require substantial cooling at meaningful average powers. A laser diode pumped laser is more efficient (<10% wall plug to optical), requires considerably less cooling, is more compact, and has longer life. Due to these overwhelming

advantages and the substantial drop in the cost of laser diodes over the past few years, the system of choice will be diode pumped.

The next issue is to choose the right laser configuration which can generate a short pulse (100-200 ps) most efficiently and with minimal complexity. The most common technique to generate short pulses is to mode-lock a laser cavity. Mode-locking, depending on the laser material and the type of mode-locker, can generate pulses of picoseconds in duration. Typically, the energy is low and amplification is necessary. This technique will work, but it may be too complex for a fieldable system.

Another option is to compress the output pulse of a conventional Q-switched laser using Stimulated Brillouin Scattering (SBS).^{7,8} Employing a two stage SBS cell containing CCl_4 the output pulse from a 25 ns Q-switched laser was compressed to 223 ps at 15% efficiency.⁹ The 223 ps light pulse was then used to switch a LASS device at 20 MW.

Since the optical pulse width generated by a Q-switched laser is directly proportional to the length of the optical cavity, decreasing the cavity length to millimeter dimensions would enable the direct generation of short pulses without the need for a compressor. We are developing a Q-switched microlaser which can generate 200 ps pulses at a 1 kHz repetition rate. Since the laser is simply a diode-pumped Q-switched laser of millimeter dimensions, it is rugged and compact. In these compact lasers, over 10 J/cc of energy can be stored in the lasing medium. This enables the direct generation of 10-100 μJ of energy per pulse. This energy range is sufficient to switch megawatts of electrical power. Figure 4 is a photograph of the first generation Q-switched microlaser and Figure 5 shows a representative output pulse. Currently, this laser can generate a less than 1 ns pulse at 1 kHz with 1-10 μJ of energy. Modifications to this basic design are being conducted to reduce the pulse width to 100-200 ps and increase the output energy.

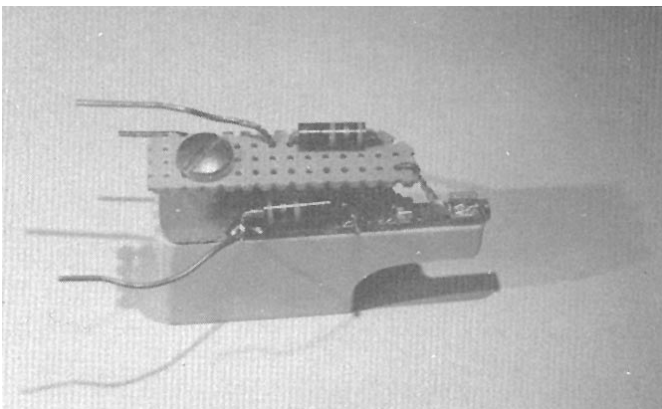


Figure 4. Photograph of the first generation microlaser. Resistors are used to charge an electro-optic crystal to perform the Q-switching.

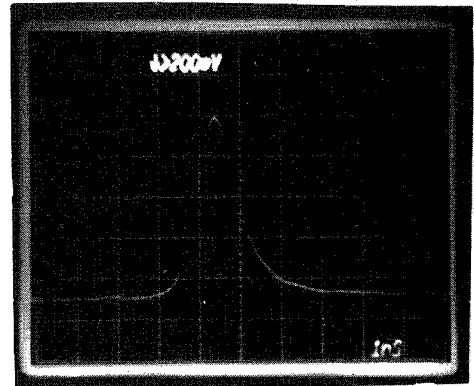


Figure 5. Output pulse from the Q-switched micro laser. Pulse width is less than 1 ns.

Since the microlaser is limited to less than 100 μJ of energy, amplification is also required to produce the energy needed for the UWB system. To this end, we are developing an all passive, multi-pass diode pumped amplifier. The basic amplifier is shown in Figure 6. It consists of a 5 mm x 5 mm x 65 mm slab of Nd:YAG on top of an array of laser diodes. When pulsed, the laser diodes produce 0.9 J of light to pump the gain medium. The entire unit (slab plus laser diodes) is housed on a 23 cm x 13 cm x 2.5 cm platform and weighs less than 2 lb. This amplifier can deliver 190 mJ of energy when incorporated in a Q-switched laser cavity. At 37 $\mu\text{J}/\text{MW}$, 190 mJ is enough for over for over 5 GW of RF power. Since the gain per pass is fixed, multi-passing of the laser beam through the gain medium is required to extract as much energy as possible. Multi-pass amplification can be achieved with a regenerative amplifier. In this approach an active electro-optical element is used to trap the beam between two mirrors in which the gain medium is placed. After a predetermined number of passes, the beam is ejected from the cavity. This is a very flexible technique in which gains of over 10^6 are achieved. However, it requires active switching of high voltage pulses to control the electro-optical elements. A simpler approach is to use an all passive, multi-pass amplification scheme developed by ECR. A schematic of a 4 pass version of this technique is shown in Figure 7. It is composed of common optical elements which occupy a footprint of 450 cm^2 . The development of new optical materials with higher Verdet constants will enable the optical components to fit on the platform with the Nd:YAG slab.

The 4 pass amplifier was assembled and tested with a mode-locked laser which delivered 15 μJ at 200 ps. After four passes through the slab, the pulse energy was increased to 17 mJ (gain of 1300) and the pulse width maintained at 200 ps. The energy developed is enough to switch 460 MW of RF power. Since less energy is being extracted than the slab can deliver, a higher gain is possible. This can be achieved by increasing the number of passes, increasing the seed energy, or by injecting multiple pulses.

REFERENCES

- ¹ O.S.F. Zucker, et.al., "High Power Light Activated Switching: Theory", in Proceedings of the 8th IEEE Pulsed Power Conference, 1991 pp. 126-129.
- ² O.S.F. Zucker, et.al., "Design and Experimental Performance of a Picosecond Rise-Time Adiabatic Transformer with Impedance Ratio of 200:1", in Proceedings of the 9th IEEE Pulsed Power Conference, 1993.
- ³ O.S.F. Zucker and I. McIntyre, "Ultra-Wideband Signal Synthesis Using Photoconductive Switches", Microwave Journal, 35, July (7) 1992.
- ⁴ F. J. Zutavern, et.al., "High Gain Photoconductive Semiconductor Switching", in Proceedings of the 8th IEEE Pulsed Power Conference, 1991, pp. 23-28.
- ⁵ K. Cardwell, et.al. "Recent Developments in Linear Photoconductive Switching", in Proceedings of the 6th HPM Conference, 1992
- ⁶ O.S.F. Zucker, et.al., "Design and Experimental Performance of a Picosecond Rise-Time Adiabatic Transformer with Impedance Ratio of 200:1", in Proceedings of the 9th IEEE Pulsed Power Conference, 1993.
- ⁷ D. T. Hon, Opt Lett 5 516 (1980)
- ⁸ V. Kubecek, K. Hamal, I. Prochazka, P. Valach, R. Buzelis, and A. Dementev, Opt Comm 73 251 (1989).
- ⁹ D. Hargis, et.al. "High Power, Subnanosecond Photoconductive Switching with a Pulsed Compressed, Q-Switched Laser", in Proceedings of CLEO/QELS Conference, Baltimore, MD 1991.

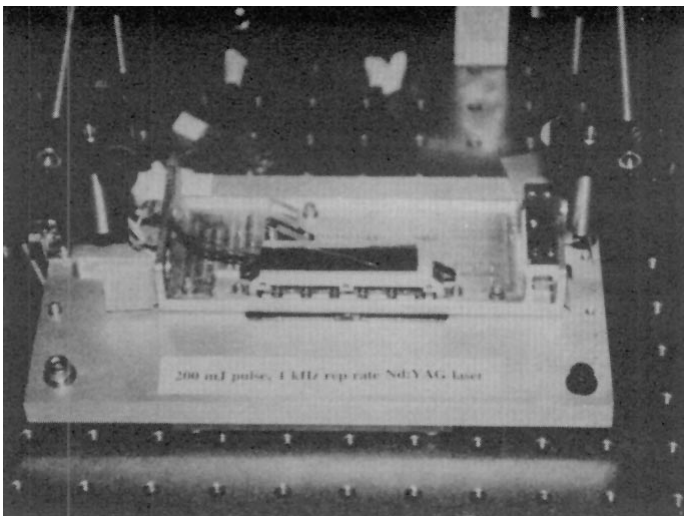


Figure 6. Photograph of the laser diode pumped amplifier which can deliver 190 mJ of energy. Amplifier is on optical bench with 1 inch hole spacing.

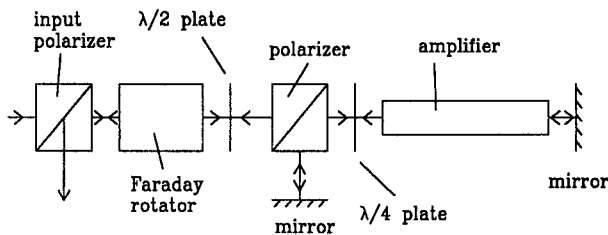


Figure 7. Schematic of four pass amplifier developed by ECR. Amplifier has shown a gain of 1300 after 4 passes.

CONCLUSIONS

All the key components required to develop an UWB generator based on light activated switching have been demonstrated. The source, transformer, and antenna have been assembled and await final testing. The laser source is being improved to meet the pulse width requirements. Testing of the complete source is targeted before 1994.

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